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Using grey intensity adjustment strategy to enhance the measurement accuracy of digital image correlation considering the effect of intensity saturation

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ABSTRACT

Intensity saturation can cause decorrelation phenomenon and decrease the measurement accuracy in digital image correlation (DIC). In the paper, the grey intensity adjustment strategy is proposed to improve the measurement accuracy of DIC considering the effect of intensity saturation. First, the grey intensity adjustment strategy is described in detail, which can recover the truncated grey intensities of the saturated pixels and reduce the decorrelation phenomenon. The simulated speckle patterns are then employed to demonstrate the efficacy of the proposed strategy, which indicates that the displacement accuracy can be improved by about 40% by the proposed strategy. Finally, the true experimental image is used to show the feasibility of the proposed strategy, which indicates that the displacement accuracy can be increased by about 10% by the proposed strategy.

1. Introduction

Digital image correlation (DIC) is a full-field, non-contact measurement method [1], which possesses the advantages of low environmental requirement, simple optical system and high measurement accuracy [2–8]. DIC measurement accuracy is affected by the quality of speckle image [9,10], such as the image contrast, the image grey intensity distribution, the speckle size and the speckle density.

To understand the effect of speckle image's quality on DIC measurement accuracy, some features of speckle image have been studied. For example, the speckle size was investigated by Wang et al. [11], who suggested 3–5 pixels as the ideal speckle size. The quality of speckle image was studied by Pan et al. [12], who proposed that the mean intensity gradient could assess the quality of the speckle image. These results can be used to assess the speckle image's quality. However, the quality of the speckle image can degrade in practical application.

In practical application, the strong illumination can make some pixels saturated, reduce the image contrast, decrease the grey intensity gradient, and even cause the decorrelation phenomenon in DIC calculation. In DIC, the zero mean normalised sum of squared differences (ZNSSD) correlation criterion was used to remove the illumination variation effect [13]. Peng et al. [14] proposed variables based sum of squared differences (VSSD) correlation criterion to decrease the effect generated by illumination variation. It was indicated that the VSSD approach can achieve a similar accuracy as that of the ZNSSD method in illumination variation. However, the obtained accuracy in the case of noise is not the same because the VSSD approach is more sensitive to noise [15]. Xu et al. [16] used image gradients to reduce the effect of illumination variation. Guo et al. [17] proposed that the stationary wavelet transform can be used to decrease the effect of illumination variation. Furthermore, recently, Simončič et al. [15] proposed a novel method for whole-field displacement measurement considering the effect of illumination variation, which included the illumination variation in the inverse compositional Gauss Newton minimisation procedure to improve the computational efficiency. However, the above strategies did not consider the saturated pixels caused by illumination variation, which exists in practical experiments and applications.

In the present paper, the grey intensity adjustment strategy has been proposed to deal with the effect of saturated pixels, which can recover the truncated grey intensities from the surrounding pixels around the saturated pixels. In addition, the simulated speckle patterns and the true experimental images are used to verify the efficacy and feasibility of the proposed strategy.

2. Grey intensity adjustment strategy

In practical applications, the decorrelation phenomenon can be caused by the saturated pixels, thus decreasing the image contrast and image grey gradient. In the proposed grey intensity adjustment strategy, the saturated pixel is first selected, which is based on the assumption that its grey intensity is the maximum such as 255 for an 8-bit image.

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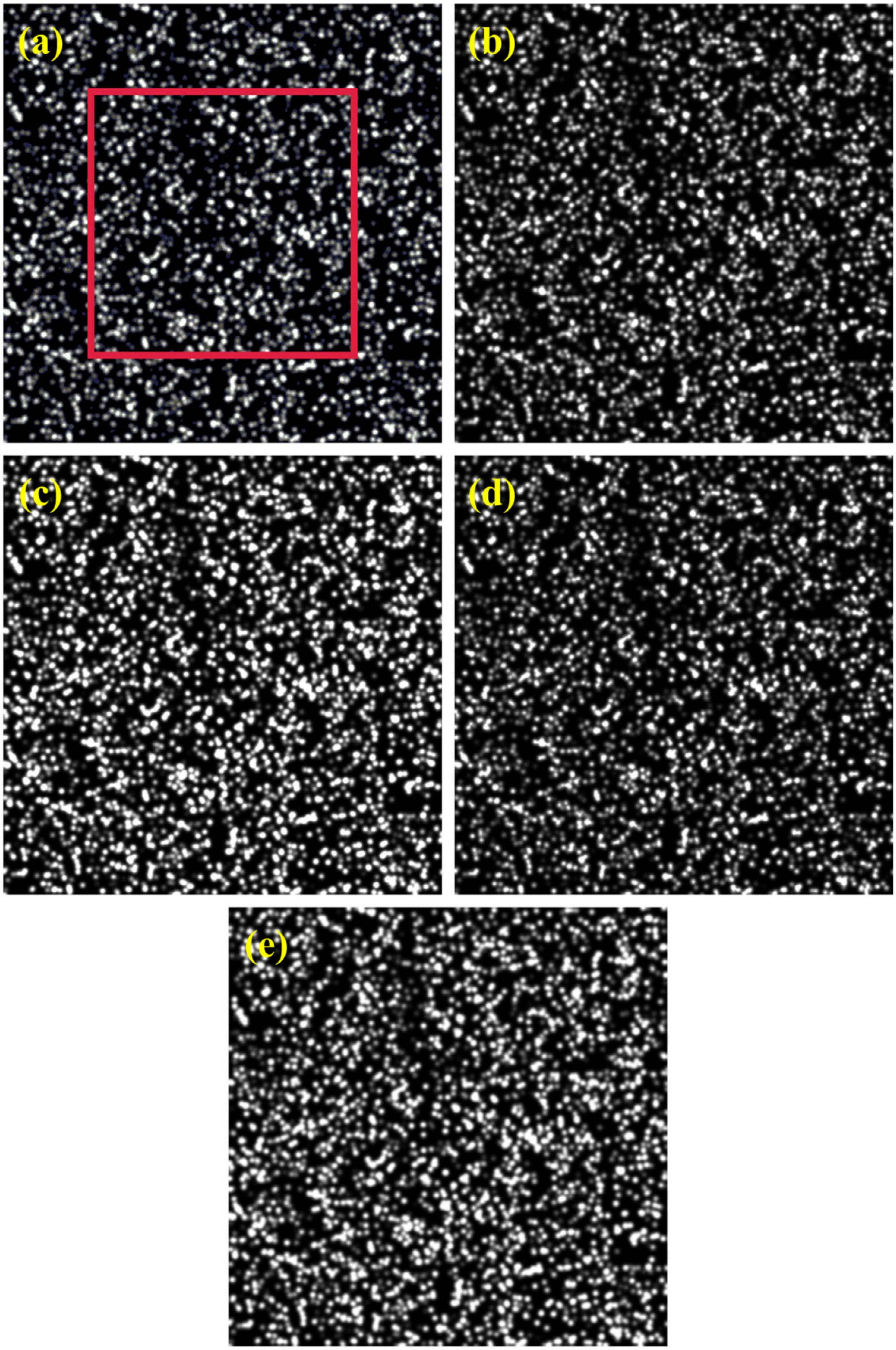

Fig. 1. (a) Reference speckle pattern (red rectangle denotes the area of interest (AOI)); (b) deformed speckle pattern; (c) deformed speckle pattern with the grey intensities increased by about 50%; (d) deformed speckle pattern in Fig. 1(c) processed by the proposed strategy; (e) deformed speckle pattern in Fig. 1(c) filtered by mean filter.

The mathematical expression is as follows:

$$\begin{cases} G'(i,j) = 255, & if\ G(i,j) = 255 \\ G'(i,j) = 0, & if\ G(i,j) < 255 \end{cases}, \tag{1}$$

where G denotes the grey intensity of each pixel in the deformed speckle pattern and G' is the grey intensity of each pixel after the above operation; i,j denotes the pixel coordinate. The truncated grey intensity of the saturated pixel is then calculated according to those of the surrounding pixels around the saturated pixel. The mathematical expression is as follows:

$$\begin{cases} G''(i,j) = \frac{1}{8}\begin{bmatrix} G'(i-1,j-1) + G'(i-1,j) + G'(i-1,j+1) \\ +G'(i,j-1) + G'(i,j+1) + \\ G'(i+1,j-1) + G'(i+1,j) + G'(i+1,j+1) \end{bmatrix}, & if\ G'(i,j) = 255 \\ G''(i,j) = 0, & if\ G'(i,j) < 255 \end{cases}, \tag{2}$$